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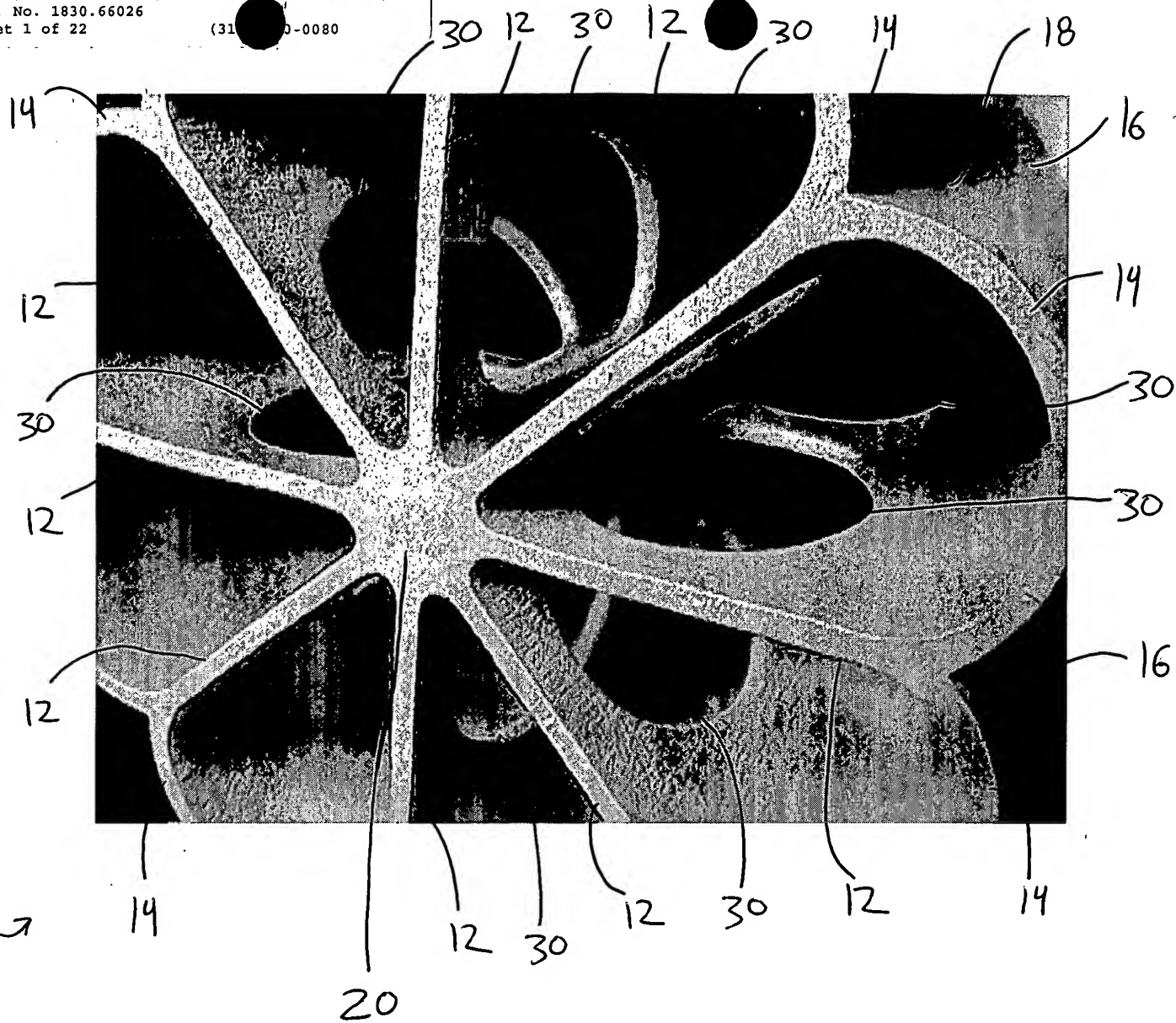


FIG. 1

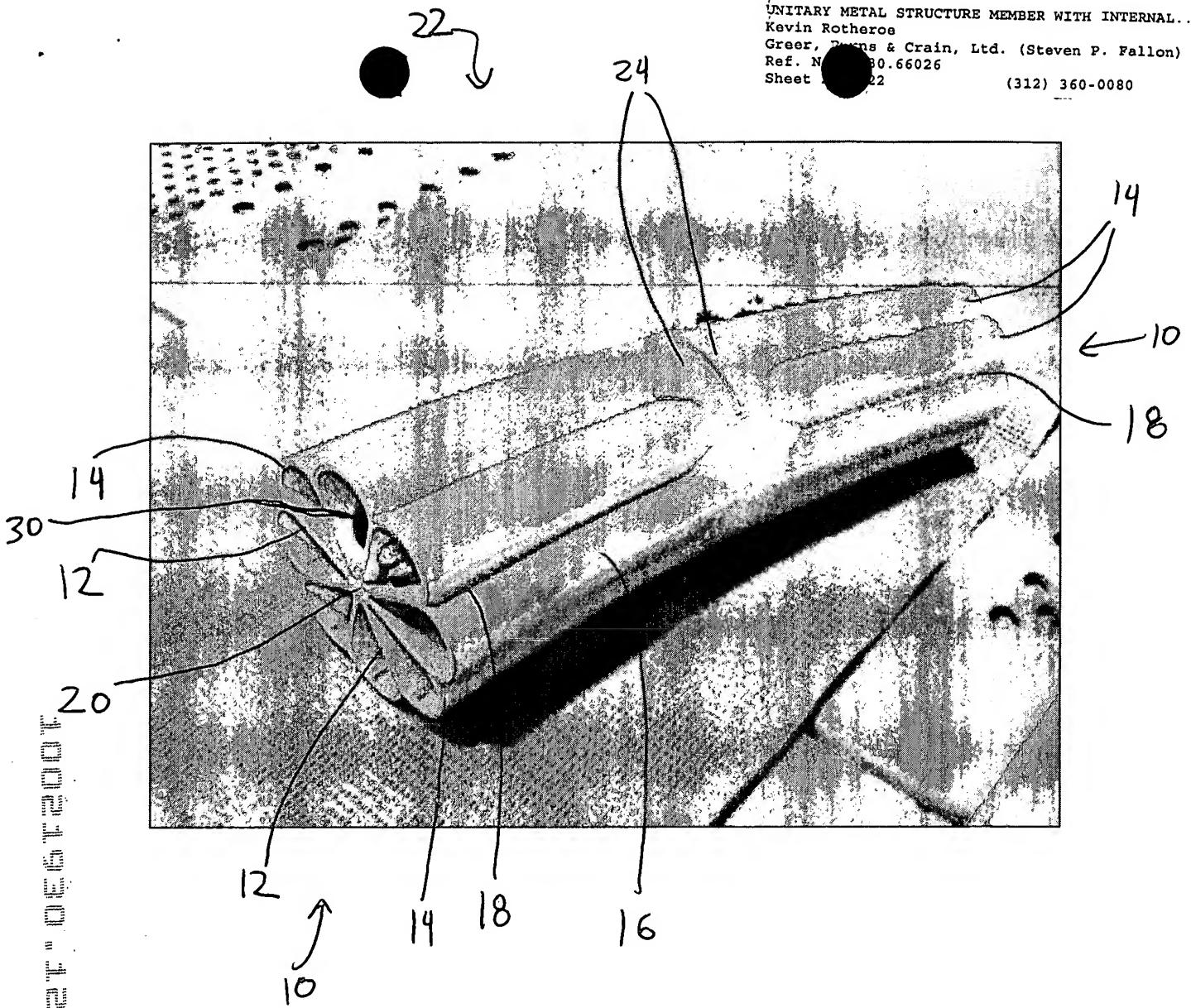


FIG. 2

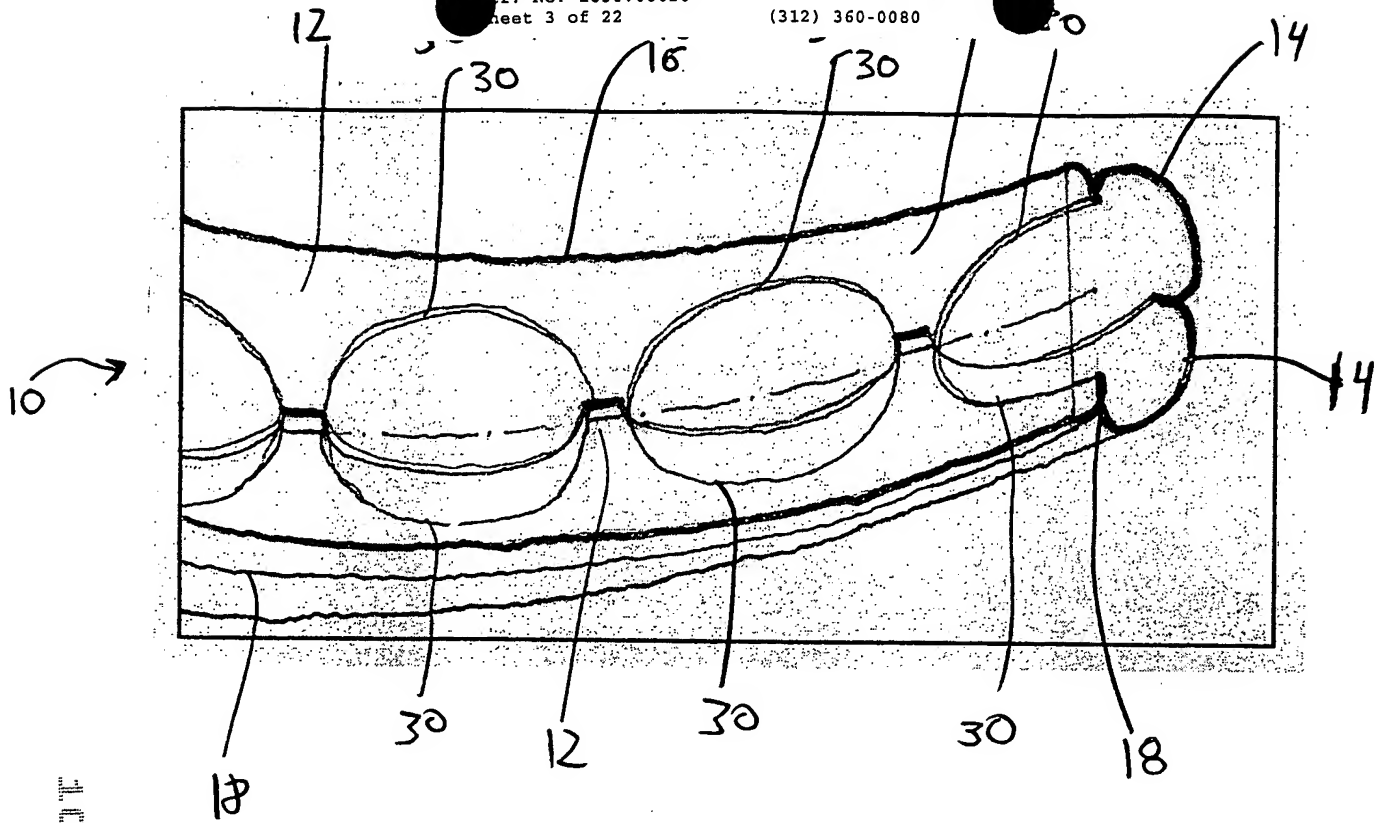


FIG. 3

FIG. 3

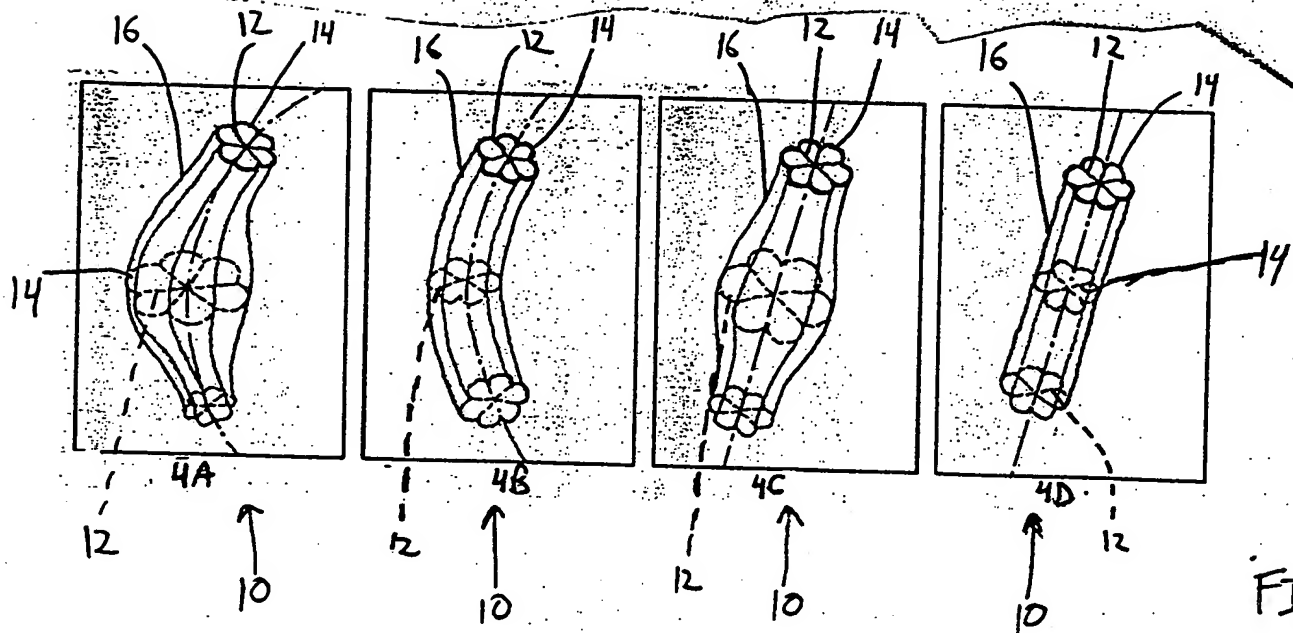
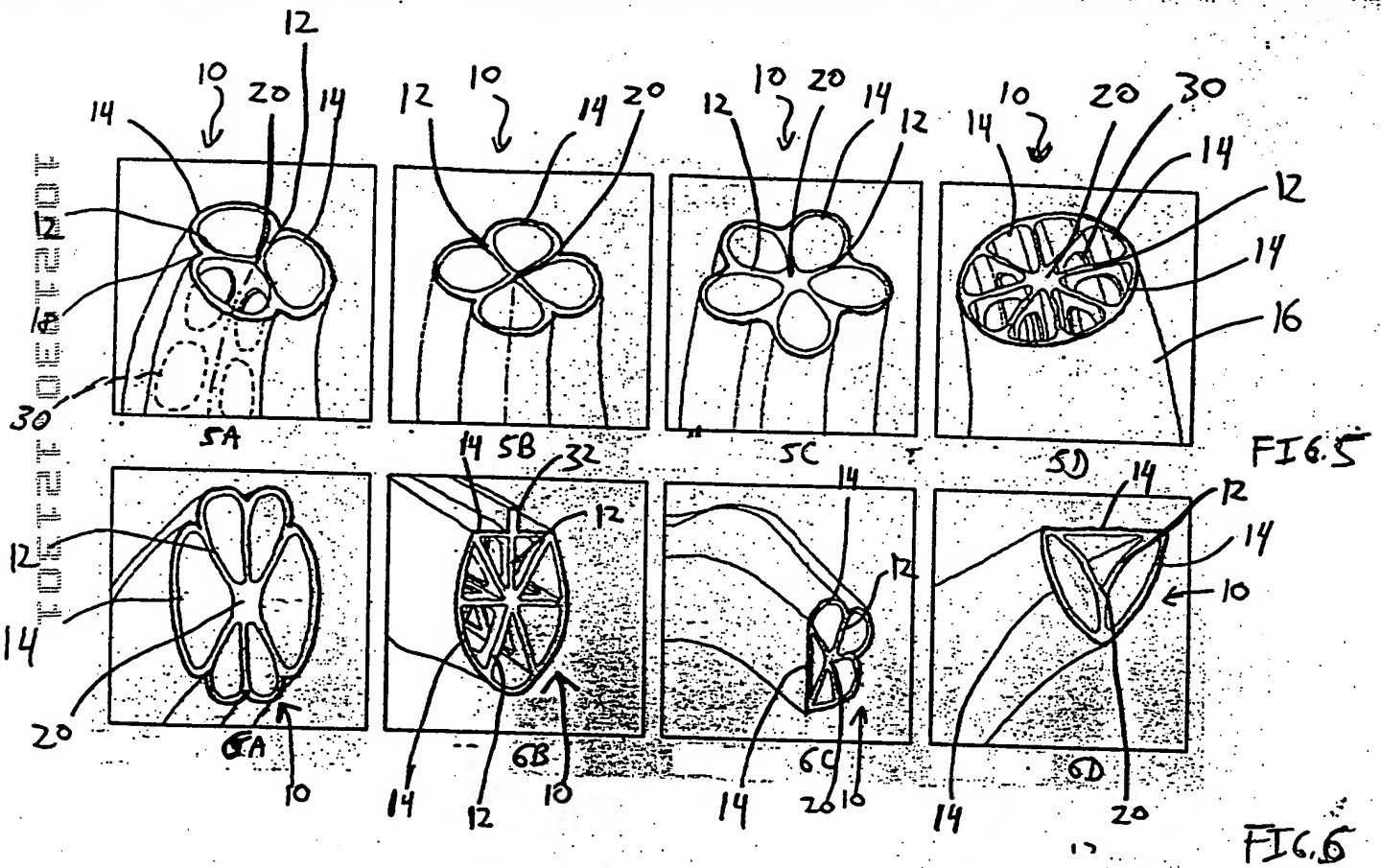
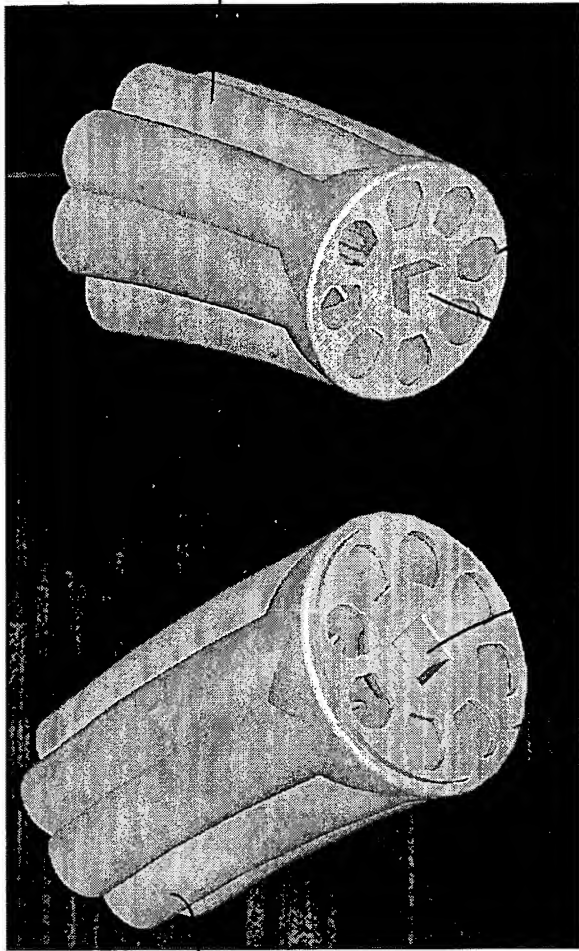


FIG. 4

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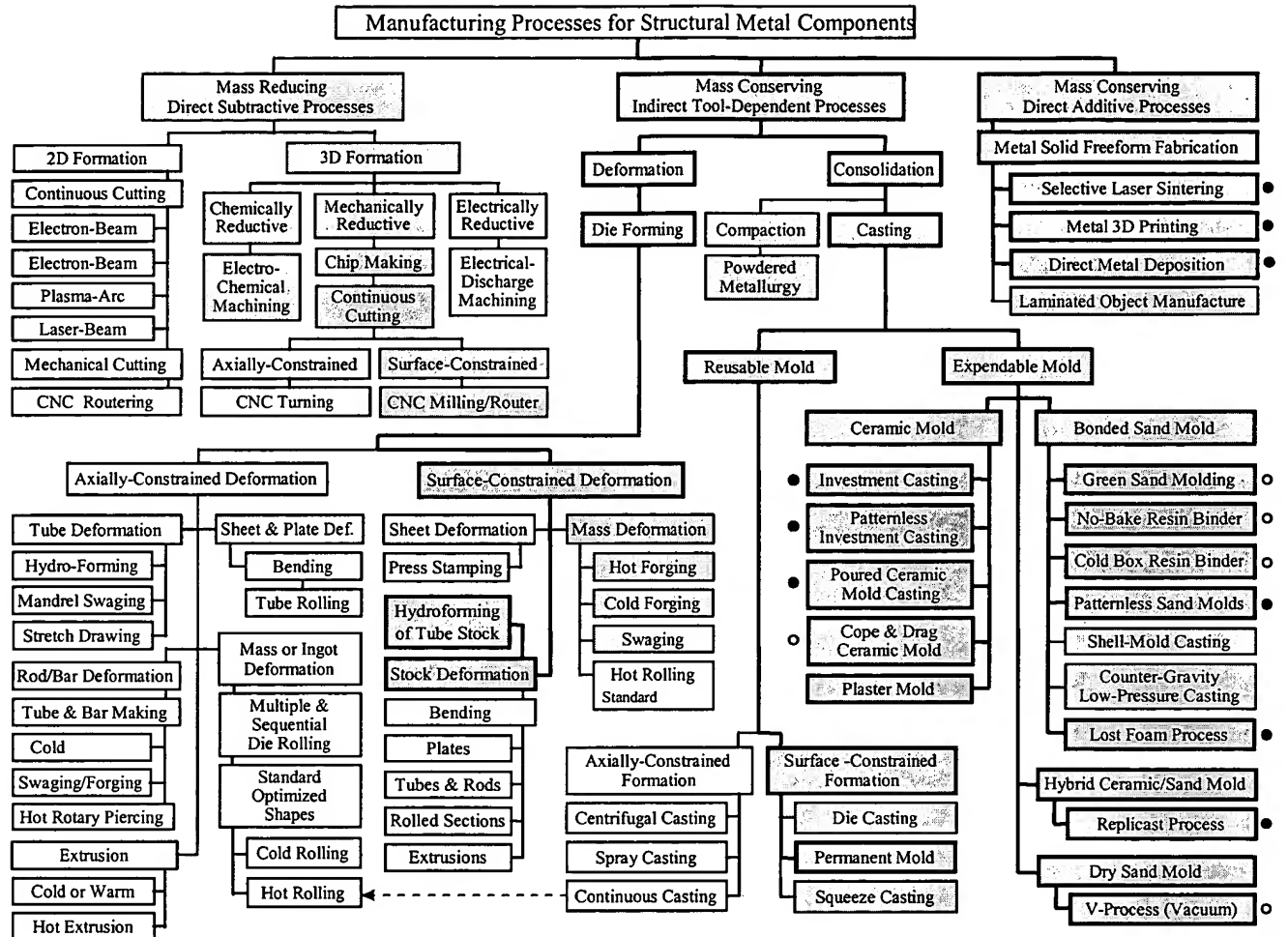
24

16

FIG. 7

FIG. 7

FIG. 8

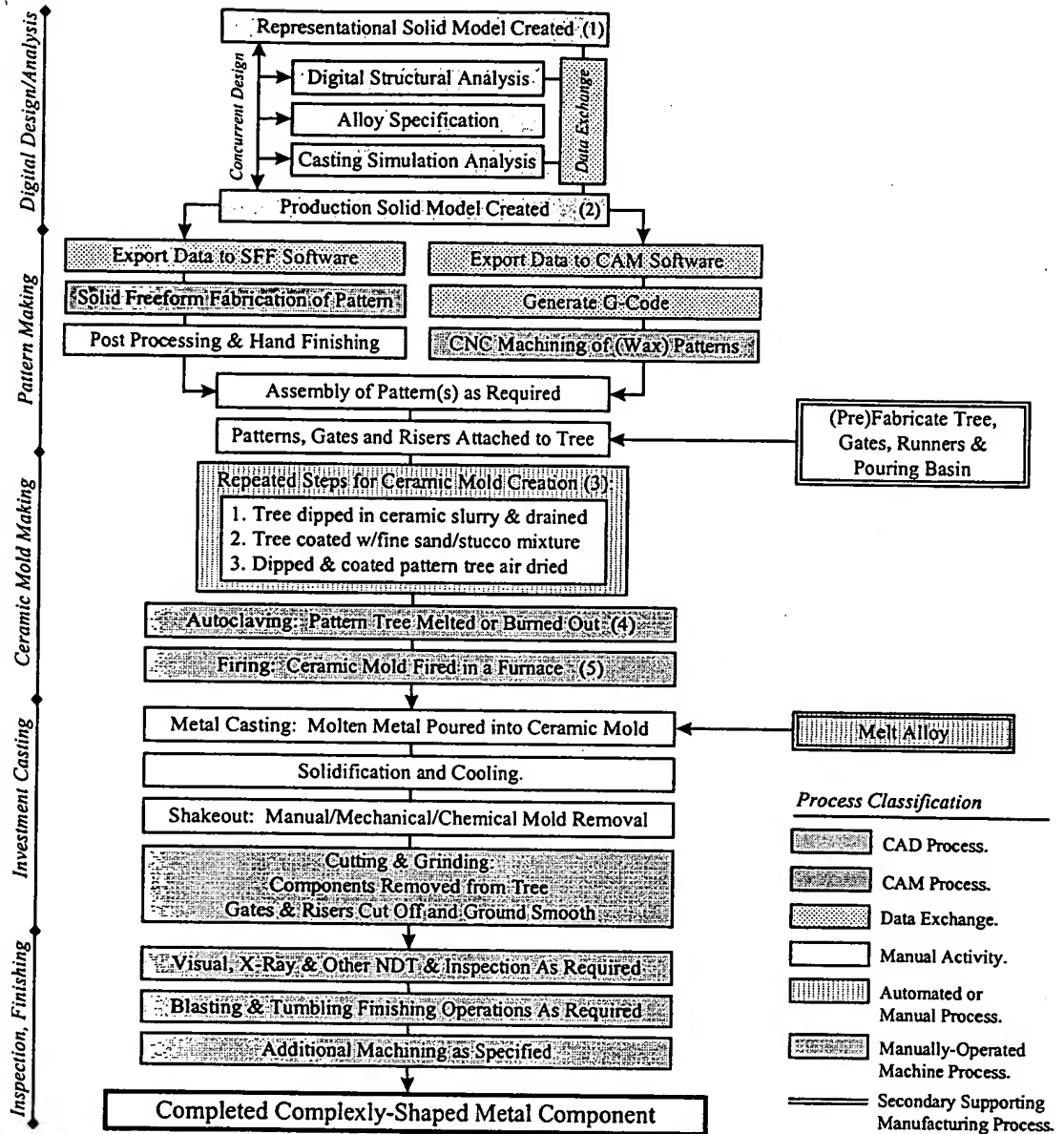


- Process with Capacity to Produce Complexly-Shaped Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubular as well as Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubes with Very Limited Internal Features.
- Process with Capacity to Produce Complexly-Shaped Tubes with Extensive Internal Features.
- Process with No Capacity to Produce Complexly-Shaped Solid or Tubular Components.

| Tooling Classification | | | | | | Process Status | | Fundamental Computer-Aided Manufacturing Processes for Complexly-Shaped Metal Structural Components: | | | | Capacity to Produce Freeform Components: | | Completely-Shaped Solids | Freeform Tubes | Tubes w/ Internal Features |
|------------------------|-----------|-----------|-----------------|--------------|--------------------|----------------|-------------|--|-------|---|--|--|--|--------------------------|----------------|----------------------------|
| Hard Die | Hard Mold | Soft Mold | Expendable Mold | Hard Pattern | Expendable Pattern | No Tooling | Established | Emerging | R & D | | | | | | | |
| | | | | | | | | | | <u>Direct Production Processes:</u> | | | | | | |
| | | | | | | | | | | 1 | 3D Data → Additive Formation → Component | | | | | |
| | | | | | | | | | | 2 | 3D Data → Subtractive Formation → Component | | | | | |
| | | | | | | | | | | <u>Direct Expendable Mold Processes (Direct Tooling):</u> | | | | | | |
| | | | | | | | | | | 3 | 3D Data → Additive Formation → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 4 | 3D Data → Subtractive Formation → Expendable Mold → Component | | | | | |
| | | | | | | | | | | <u>Indirect Expendable Mold Processes:</u> | | | | | | |
| | | | | | | | | | | 5 | 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 6 | 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 7 | 3D Data → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 8 | 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 9 | 3D Data → Additive Formation → Master Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 10 | 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 11 | 3D Data → Additive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | 12 | 3D Data → Subtractive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component | | | | | |
| | | | | | | | | | | <u>Direct Permanent Mold Production Processes:</u> | | | | | | |
| | | | | | | | | | | 13 | 3D Data → Additive Formation → Permanent Mold → Component | | | | | |
| | | | | | | | | | | 14 | 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Component | | | | | |
| | | | | | | | | | | 15 | 3D Data → Subtractive Formation → Permanent Mold → Component | | | | | |
| | | | | | | | | | | <u>Direct Permanent Die Production Processes:</u> | | | | | | |
| | | | | | | | | | | 16 | 3D Data → Additive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 17 | 3D Data → Additive Formation → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 18 | 3D Data → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | <u>Indirect Permanent Die Production Processes:</u> | | | | | | |
| | | | | | | | | | | 19 | 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 20 | 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 21 | 3D Data → Subtractive Formation → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 22 | 3D Data → Additive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |
| | | | | | | | | | | 23 | 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component | | | | | |

Note: Permanent mold processes have the capacity to produce freeform metal tubes if sand cores are used, which is an established method. As with other pattern & mold-based processes, the capacity to produce internal features is limited by pattern or product removal.

TOP OF DEFEET



Finish & Inspect Post-Processing Casting Ceramic Mold Making Pattern Making Data Transfer Digital Design

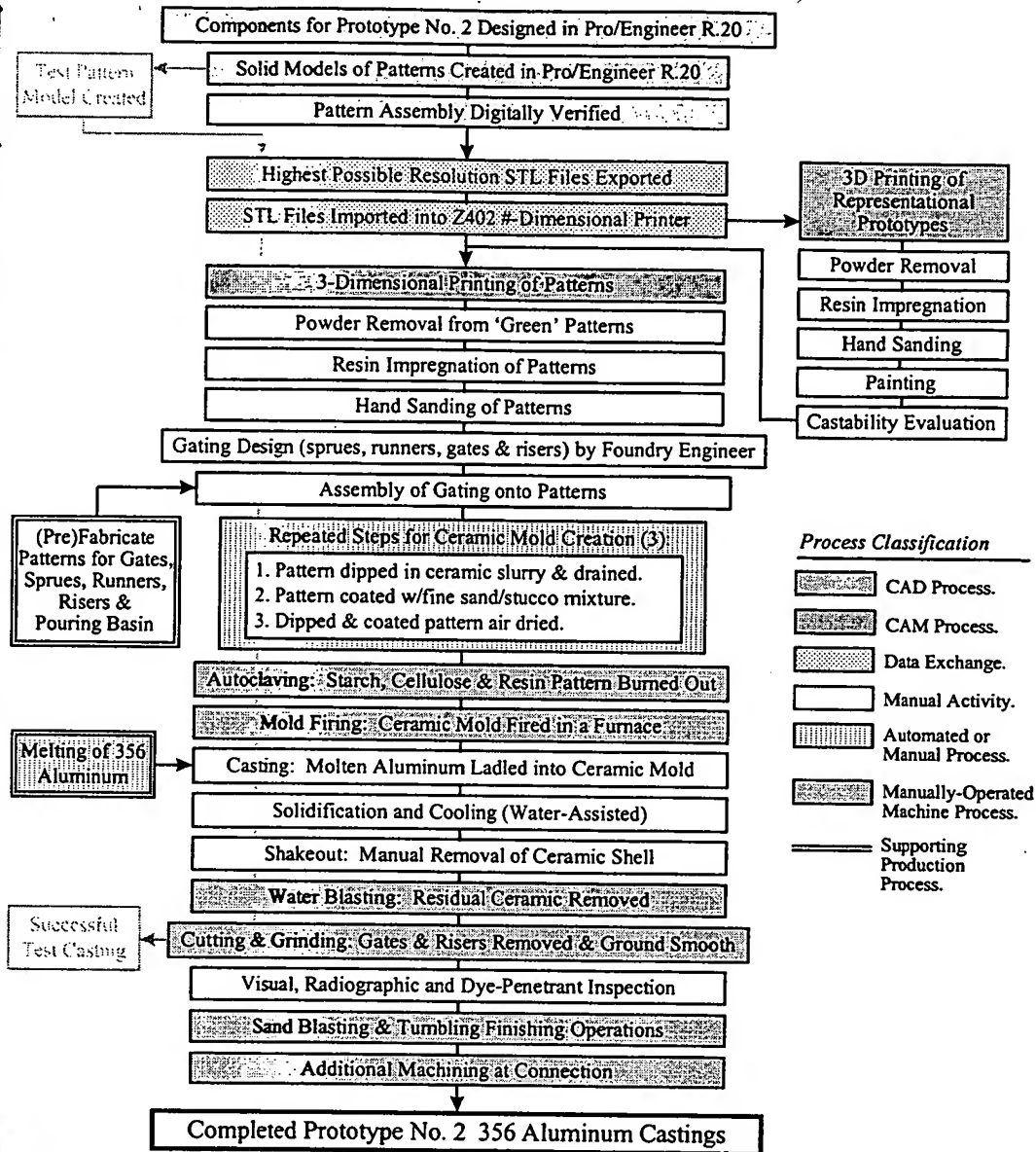


FIG 11

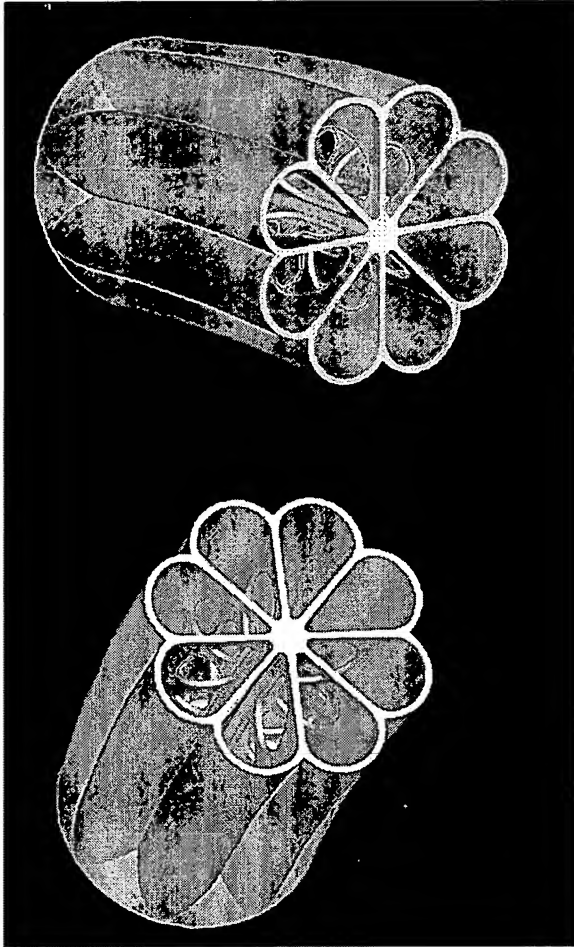


FIG. 12

1002490143001

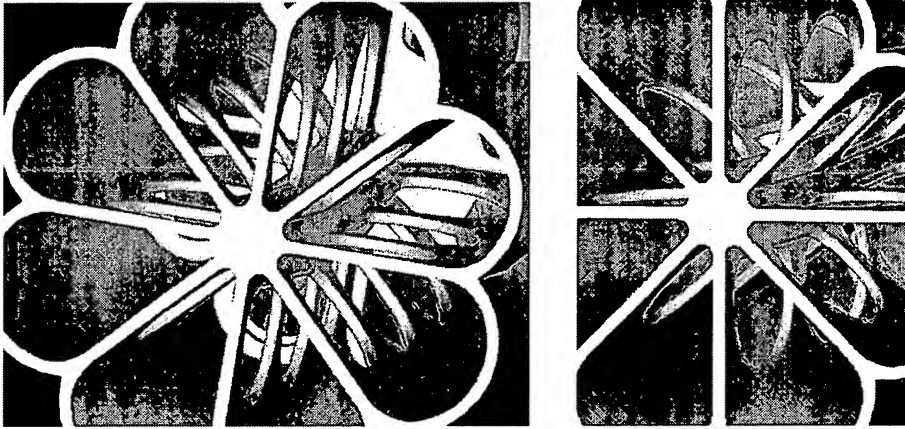


FIG. 13

10024930-121304

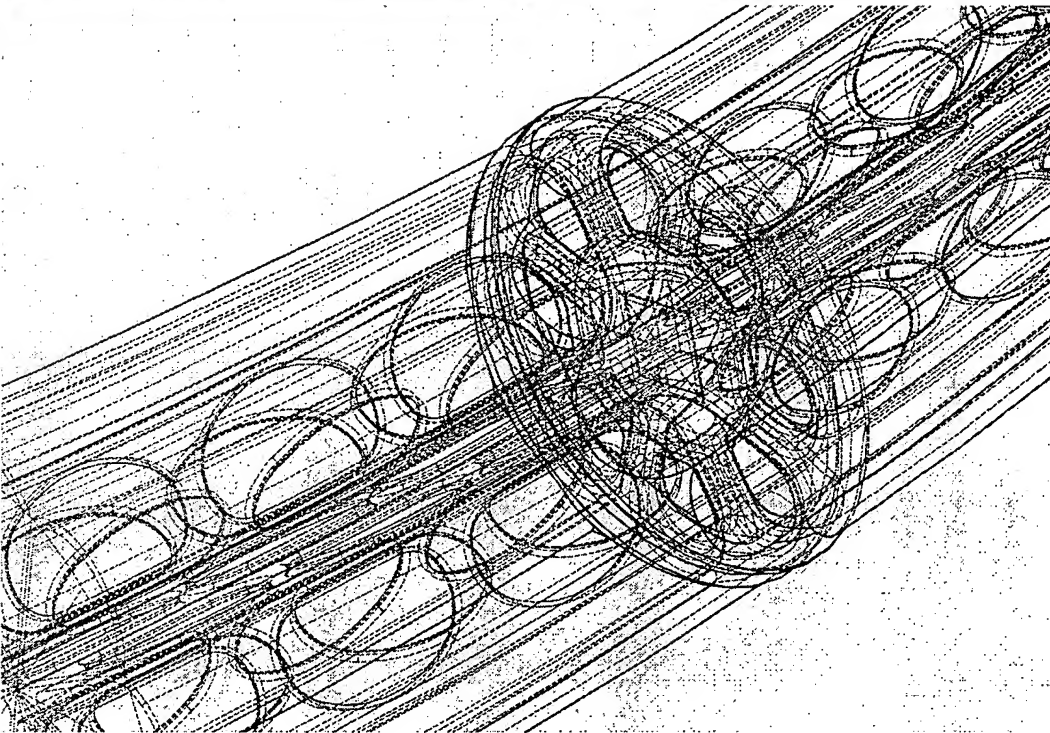
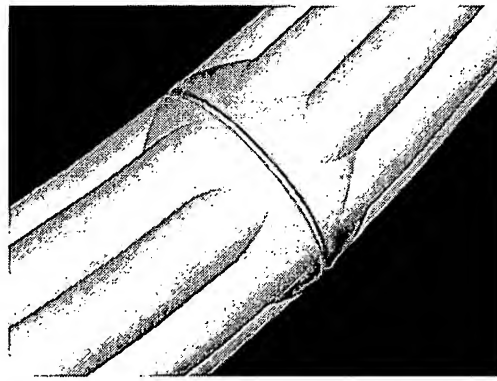
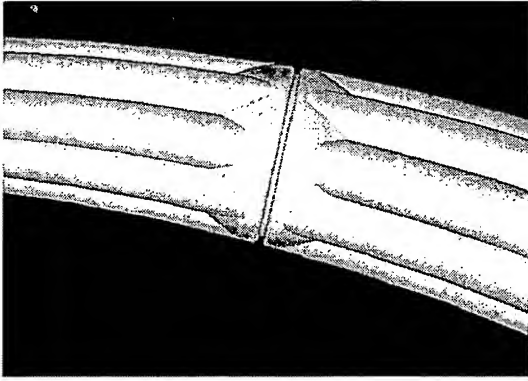


FIG. 14

10021930.13.1301
FOET 22 OF 22

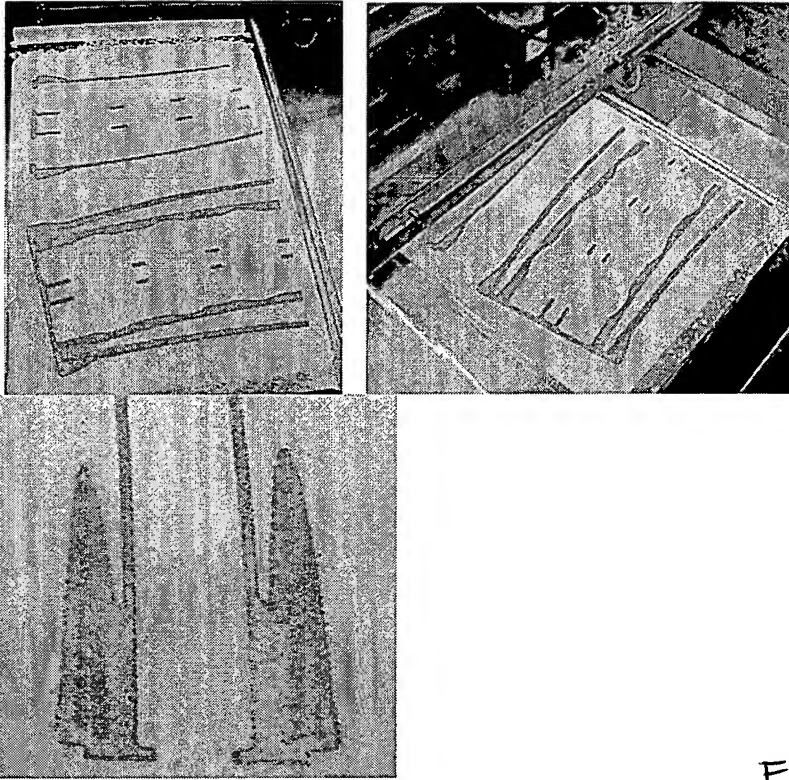


FIG. 15

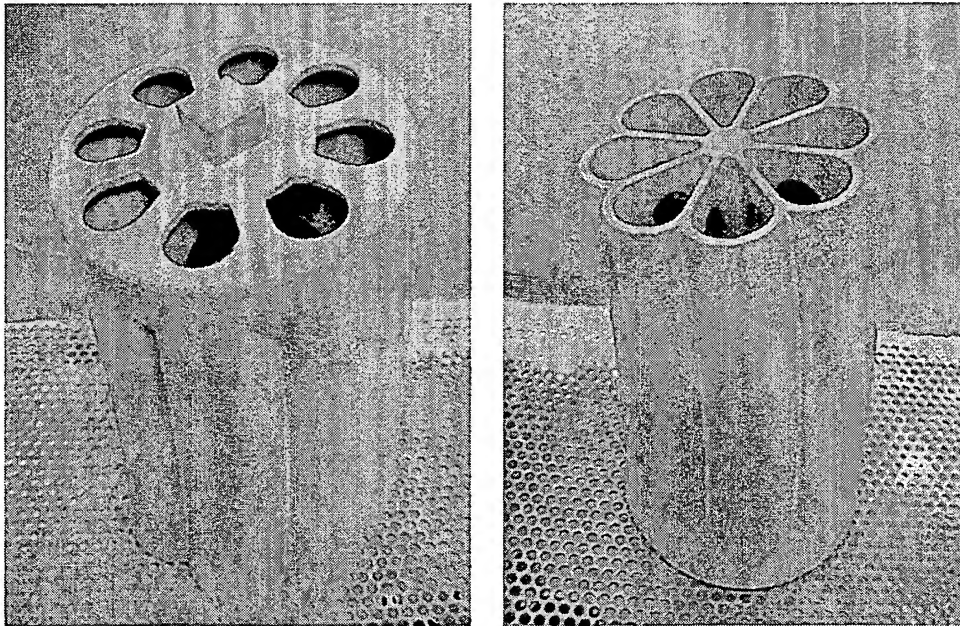


FIG. 16

1830.66026-124304

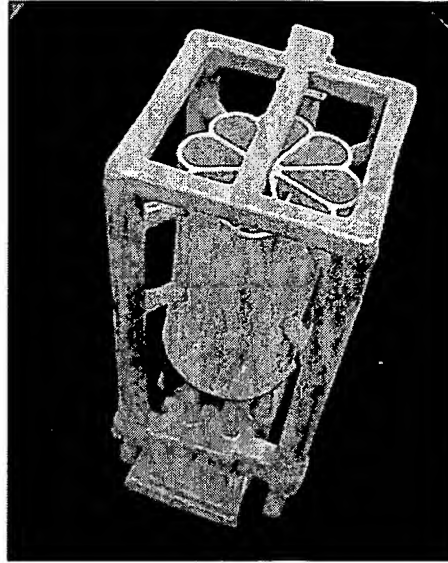
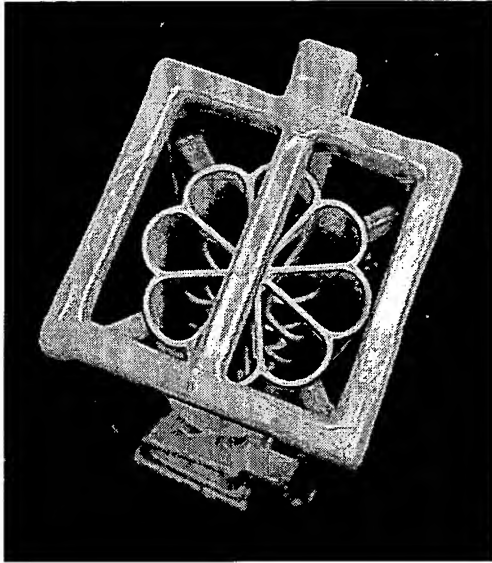


FIG. 17

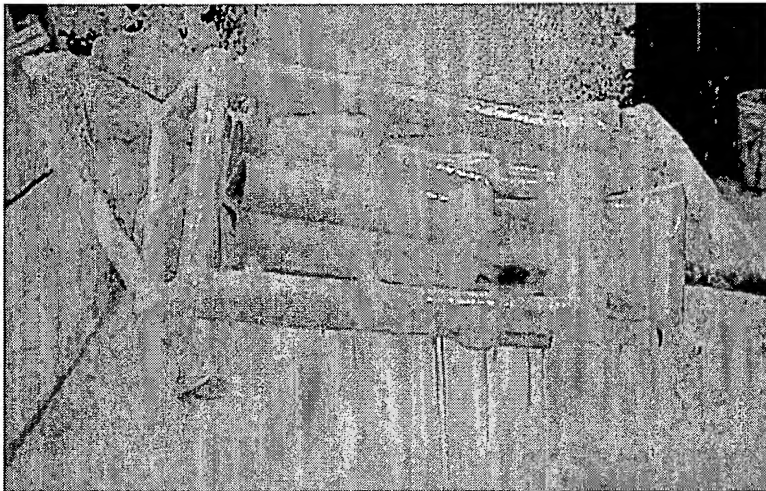


FIG. 18

FIG. 17 (left view)

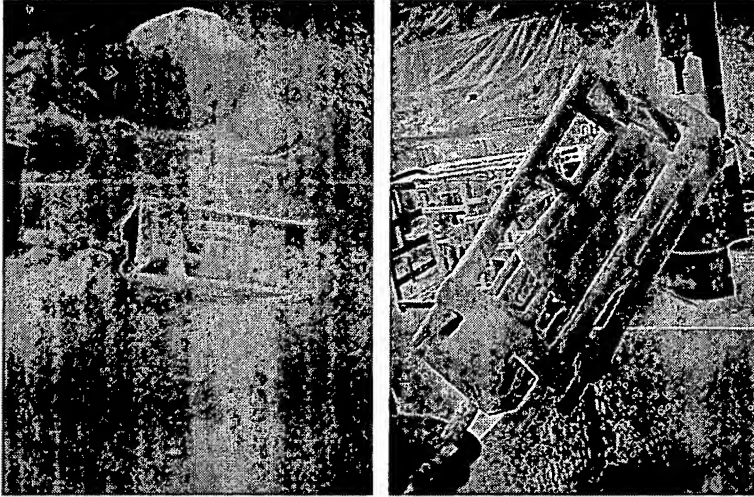


FIG. 19

10021530 121301

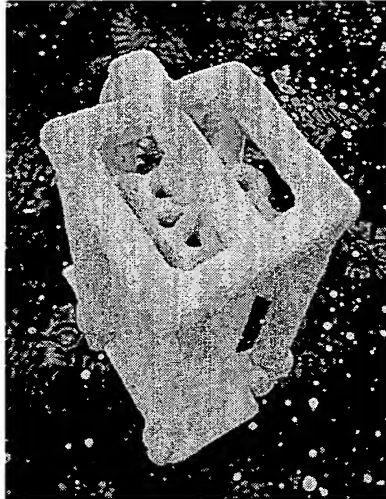
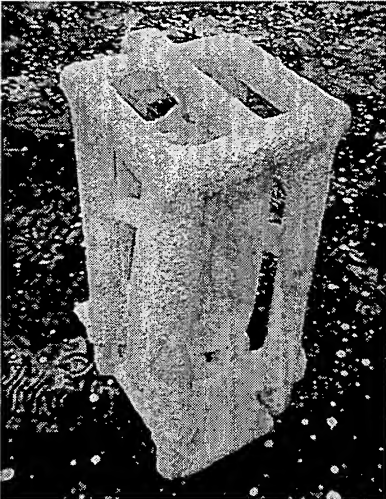
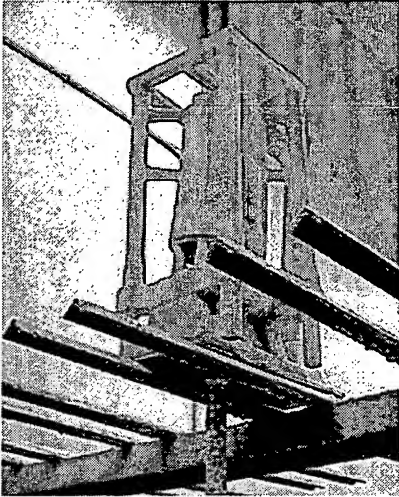


FIG. 20



FIG. 21

FIG. 22



FIG. 22

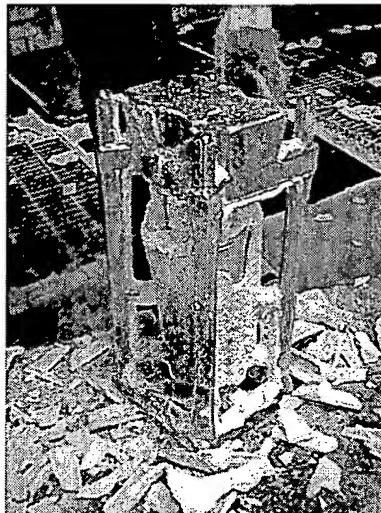
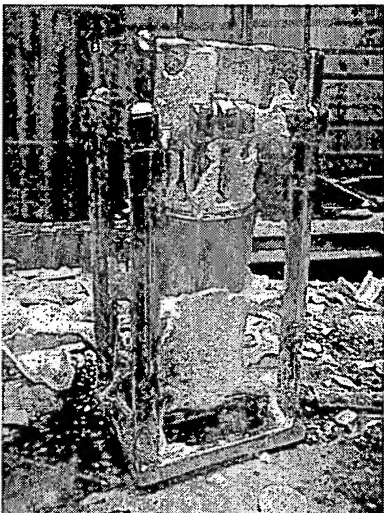


FIG. 23

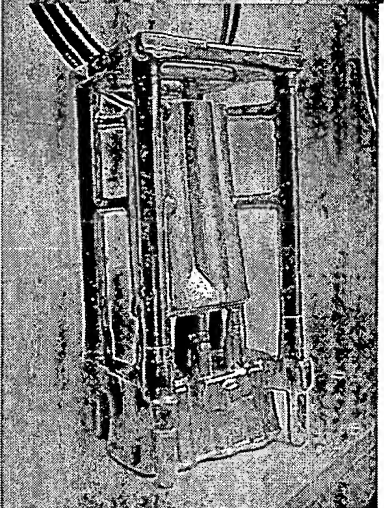


FIG. 24

FIG. 22

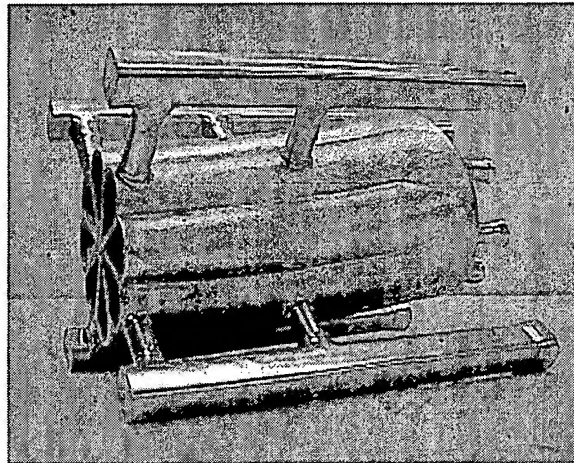
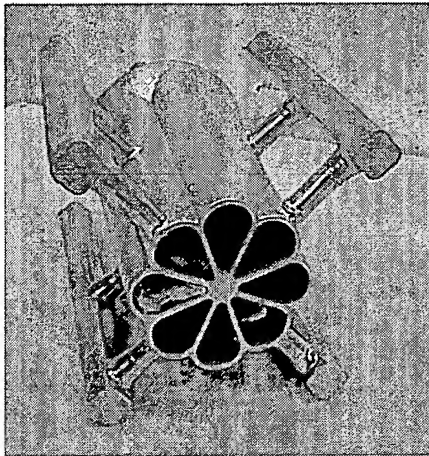


FIG. 25

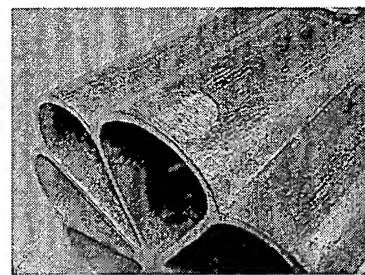
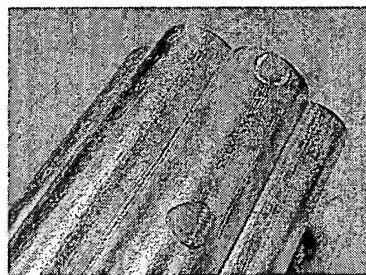
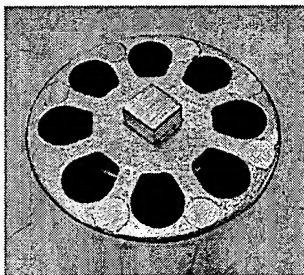


FIG. 26

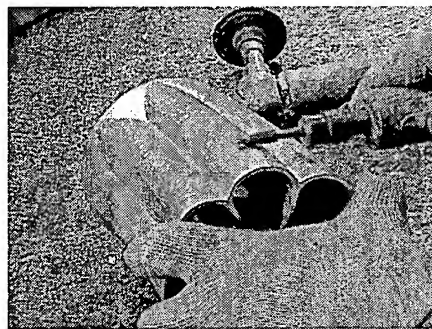
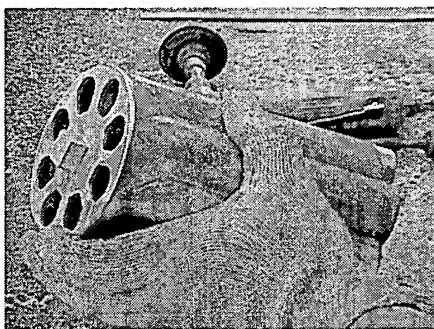


FIG. 27

FIG. 25

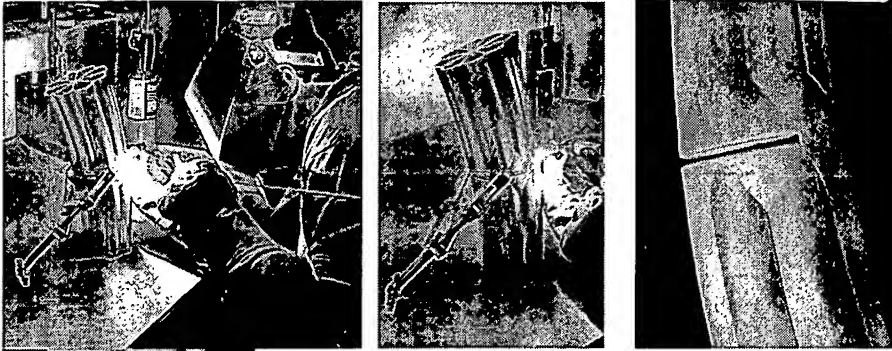


FIG. 28



FIG. 29

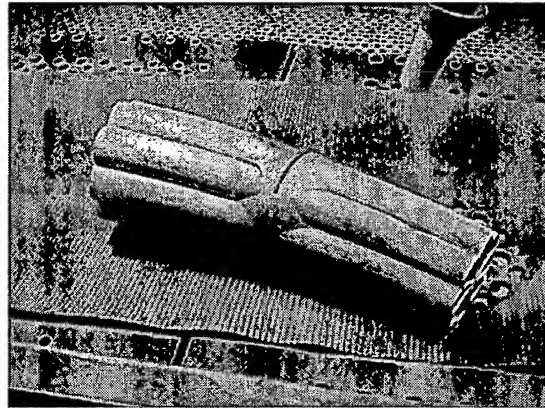
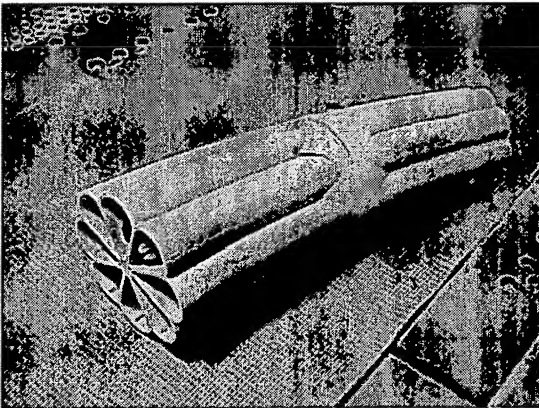
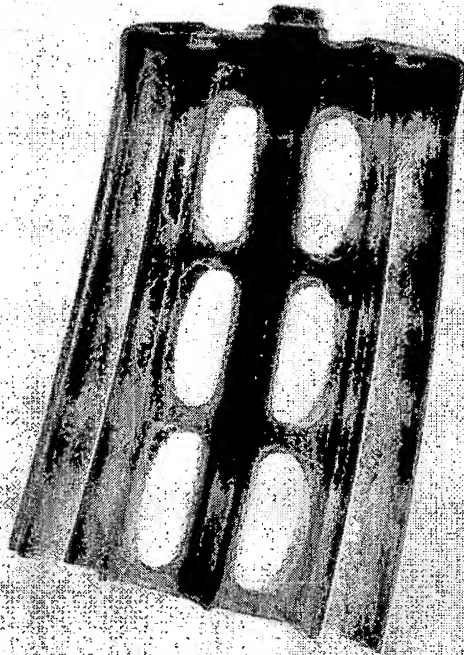


FIG. 30

UNITARY METAL STRUCTURE MEMBER WITH INTERNAL COMPONENTS



31A



31B

FIG. 31

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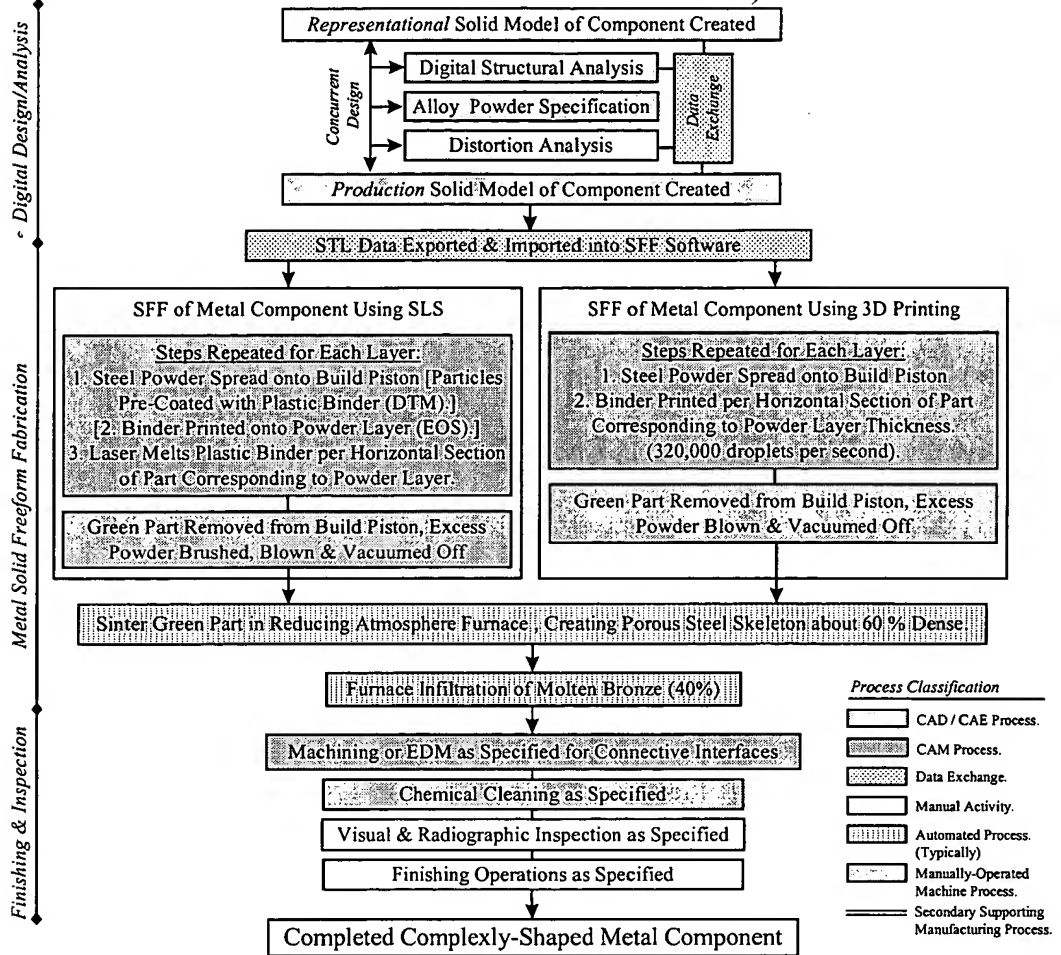


FIG. 32